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ICAM PROGRAM PROSPECTUS

1 DECEMBER 1977

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NOTICE

This report has been reviewed and is approved for publication.

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The U.S. Air Force's program for Integrated Computer-Aided manufacturing (ICAM) was brought about by needs and pressures in state-of-the-art technologies, economics, increasing human limitations, aerospace design and manufacturing complexity, computer developments, and competition from abroad. These factors will bring ICAM on the American scene eventually, with or without an Air Force role. However, since the government is a large customer of manufacturing production, and since the ICAM program is a logical extension of a

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previous Air Force project, the ICAM program is a practical effort to greatly shorten the implementation timespan for incorporation of compatible and standardized techniques and to provide unified direction for industry. ICAM is essentially a program and development plan to produce systematically related modules for efficient manufacturing control. Modules may be separately developed, and may be individually implemented in industry, with short-term gains. But the primary benefits of the modular structure will only be evident in a fully-integrated system. The private sector is heavily involved in the program coordination, in which a "wedge" of sheet metal fabrication is being modeled and developed to demonstrate computer coordination at all levels of design and manufacturing. In addition to substantial cost savings and improved management control, ICAM will permit designs in which parts are computer-examined for performance evaluation and economical fabrication, and in which the computer will permit rapid examination of management choices in the detailed planning of manufacturing.

CONTENTS

FOREWORD

Integrated Computer-Aided Manufacturing (ICAM) is an Air Force Materials Laboratory, Air Force Manufacturing Technology Division program funded at approximately $75 million through fiscal 1982. The purpose of this prospectus is to introduce the ICAM program and to promote understanding and acceptance of the need -- and the program's right to perform in accordance with this need. Comments will be appreciated.

This report has been reviewed and approved.

ICAM
PROGRAM
PROSPECTUS

I. ABSTRACT

The U.S. Air Force's program for Integrated Computer-Aided Manufacturing (ICAM) was brought about by needs and pressures in state-of-the-art technologies, economics, increasing human limitations, aerospace design and manufacturing complexity, computer developments, and competition from abroad. These factors will bring ICAM on the American scene eventually, with or without an Air Force role. However, since the government is a large customer of manufacturing production, and since the ICAM program is a logical extension of a previous Air Force project, the ICAM program is a practical effort to greatly shorten the implementation timespan for incorporation of compatible and standardized techniques and to provide unified direction for industry. ICAM is essentially a program and development plan to produce systematically related modules for efficient manufacturing control. Modules may be separately developed, and may be individually implemented in industry, with short-term gains. But the primary benefits of the modular structure will only be evident in a fully-integrated system. The private sector is heavily involved in the program coordination, in which a "wedge" of sheet metal fabrication is being modeled and developed to demonstrate computer coordination at all levels of design and manufacturing. In addition to substantial cost savings and improved management control, ICAM will permit designs in which parts are computer-examined for performance evaluation and economical fabrication, and in which the computer will permit rapid examination of management choices in the detailed planning of manufacturing.

II. INTRODUCTION

This prospectus, although it emphasizes substantial technical matters, is intended as a realistic and objective overview of the U.S. Air Force's program in Integrated Computer-Aided Manufacturing (ICAM). Sufficient detail is provided to give meaning to the program's rationale, characteristics, implementation, and anticipated pay-off. The scope of the program is very large; to provide perspective, a "Need for ICAM" section briefly describes the factors which are leading industrial societies in general, and the United States in particular, toward an integration of computer functions and computer aids in the process of manufacturing.

III. NEED FOR ICAM

A. STATE-OF-THE-ART

The state-of-the-art of elements of aerospace design, data banks on materials and their properties and characteristics, manufacturing technology, logistics management, and human limitations are briefly discussed below. This status, super-imposed on explosive new developments in electronics and computer capability, shows a clear need for an overall unifying concept of the type proposed in the Air Force's ICAM program.

Aerospace Design

Advances in aerospace systems initially require conceptual design. For meaningful follow-on, there must then be feasibility studies and eventually hardware embodiment. Both of these two latter stages require design efforts based on compatibility between desired performance specifications and both technological and materials constraints, among others. In modern aerospace systems these design elements have become so complex that computers are now a recognized necessity to provide timely analyses and performance predictions of the many trial designs considered during a project. However, no less vital is the mutual interactive communication of such design information between the interdisciplinary personnel, consisting of designers, scientists, engineers, and project managers, on a typical corporate working team. This problem of inter-communication has been considered to be basically solvable by computer software, and, since 1975, has been addressed by the Integrated Program for Aerospace-Vehicle Design (IPAD) project of NASA (1). However, the computer-linked coordination of design activity of this type with the

materials technology and manufacturing processes which are needed to translate what are basically conceptual images into practical working embodiments remains unaddressed by anyone.

Information Data Banks

Materials of all types, both metallic and non-metallic, structural and non-structural, are the basic building blocks of all hardware and the energy sources for their operation. The important properties of such materials range over a wide gamut, including fundamental -- electrical, magnetic, thermal, physical, chemical -- as well as utilitarian characteristics such as machinability, cost, availability, sources of supply, stock shapes, toxicity, performance history, and others. This broader spectrum of information is not available from any single source, even on a single material. Comparisons of various materials across a wide range of characteristics (beyond properties) requires laborious collection from various sources.

Groups of such characteristics information on materials are documented and stored in various specialized data banks maintained by government, industrial, and academic institutions, both national and international in scope (2). Although the majority of these information storage facilities do have now some mode of computer searching, the communication interface with both design and manufacturing operations is still almost exclusively through human intervention and data transfer with attendant costly time delays, omissions, and erroneous or incomplete data interpretation and evaluation. The balancing, comparison, and optimization of multi-parameter characteristics on any subject is basically not compatible with human thought patterns.

Manufacturing Technology

The actual conversion of raw materials and shapes to end items of proper size, configuration, and performance specifications is accomplished by the processes of manufacturing technology. Such technology has been advanced, as applicable, by techniques resulting in faster production, more uniform output, greater performance reliability, and cost efficiencies. While improved materials, better quality control and superior design have each made their contribution, the ever-increasing role of automation and computer control on processes and machines must be given the major credit for the advances recently observed. The use of numerical control (NC) and computerized numerical control (CNC) concepts have allowed use of preprogrammed or computer instructions to direct complex machining operations to highly reproducible tolerances by widely available appropriately-designed equipment with minimal human operation. The extension to automation of entire assembly operations has already begun through the increasing proliferation of "robots" in metal-working and electronics industries throughout the world (3). However, there is still too much human involvement with set-up time, raw stock selection and feeding, and product removal. The consequence is that too often each manufacturing procedure is a batch operation.

Logistics Management

Possibly the most difficult problem associated with any production system is the scheduling, distribution and maintenance of input raw materials and output finished products. Involved are ordering, storage, scheduling, transportation, and inventory control problems. For complete assemblies, such as aerospace systems, there are the same difficulties associated with spare

parts and subsystem production and logistics management. While many aspects have been the subject of computerization efforts, more or less successful, only isolated phases have been examined and no overall comprehensive system has heretofore been properly approached. An obvious appeal is that more rapid production and delivery response to users' needs for spare parts could reduce standing inventory requirements.

Human Limitations

Current aerospace systems production depends heavily on intermediate stages of human intervention, including design conceptualization, decision making, data communication, report documentation, etc., which, if computer-assisted, can be efficient. If not so aided, then these stages as well as other manned activities (such as materials and products handling) become manpower-intensive. These activities are usually relatively slow and uneconomically inefficient when compared to the automated and/or computerized components of the operation. Automated stages are being continually and increasingly improved in speed, versatility and economy. Because of these constant changes, the roles, capacities, and costs of human involvement need to be continuously re-examined.

Electronics and Computers

The increasingly rapid advances in electronics and explosive developments in computer hardware and software are easily observable on all sides. Solid state chip technology, large scale integrated circuits, and newer memory storage principles, in just the last two to three years, have revolutionized

computers and the end is not yet in sight. Micro- and mini-computers with advanced memories and peripheral auxiliary equipment can now replace larger standard computer systems at small fractions of the cost for acquisition and operation. The newer processors have less space and environmental control requirements, yet perform with greater versatility and faster rates. This new computer technology is quickly supplanting the old obsolescent systems; equally important, it is opening new horizons in performance and the handling of problems not previously amenable to computer solutions. Small inexpensive memories capable of storing millions of data words, magnetic disks which allow random access to billions of such words, and parallel processors make the integrated management of large information-handling and production-oriented systems entirely feasible.

Competition from Abroad

In response to interest by Congress in the subjects of increased productivity, competitiveness of the United States in world markets, price stability, and economic growth, the U.S. Comptroller General issued an analytical report (4) on these matters in June, 1976. It was noted that virtually everything produced in the United States is procured, in one form or another, by the Federal Government, and the Department of Defense alone obtained items or services from more than 25,000 contractors. A major portion of the items procured were made by batch processes which were amenable to automation techniques to improve productivity. The report also stressed that the U.S. rate of increase in manufacturing productivity was among the lowest in the world, a factor reflected in the consistently declining U.S. balance-of-trade position since

1971 as increased imports of high-technology products -- once a major export of the U.S. -- arrive from foreign countries.

The Comptroller General suggested that foreign competitors were moving ahead of the U.S. in applying manufacturing automation. The report took to task the national private sector for neglecting or being unaware of the situation, for taking actions not in the best interests of the U.S. economy, or for not moving fast enough to sustain the national socio-economic way of life.

In support of these criticisms, a 1975 survey (3) showed that Japan had almost three times as many manufactureres of "robot" or automation machines as the U.S. -- the ratio being 70 to 26 -- and that the European Economic Community nations exceeded the U.S. with their 33. Moreover, the Japanese have been most innovative in using the "robots" in all types of production ranging from miniature electronics and watches to complete steel mills.

Although quantity of manufacturers is not everything, it is quite evident that heroic measures are needed by American industry to keep pace with, let alone surpass, foreign competition.

B. THE AIR FORCE'S ROLE

The goals of all phases of the military-industrial aerospace partnership are to streamline, optimize and economize production and inventory response. The state-of-the-art descriptions given above clearly spell out the need for increased computerization and integration of all aspects which are amenable to this treatment. It is evident that integrated computerized design and

manufacturing capability could increase efficiency and responsiveness of industry to the needs of the consuming public and, more critically, to the requirements of the U.S. government and national security. It is also reasonable to recognize that the competition between manufacturers and the enormous start-up costs and growing pains to develop such an integration project preclude its being initiated by industry.

The Department of Defense, with its need for the latest and most efficiently-produced technological hardware, is the likely initiator and manager of such efforts. Within the Department of Defense, the Air Force has had the most pertinent experience and capability by virtue of the pioneering work of its Materials Laboratory that resulted in the development of Numerical Controlled Machine Tools (NCMT), and the APT programming language in the 1950's. The current ICAM program discussed in this prospectus is a logical extension of the earlier precedent-setting program that was also a joint effort between the Materials Laboratory and the private sector, with full mutual coordination between all interested parties.

A central program office in the Air Force will reduce wasteful and redundant independent efforts among contractors, will insure that the best technology will be applied to the most pressing critical problems, and will increase the likelihood for compatibility and/or standardization in future manufacturing systems. Air Force involvement will also shorten the time for incorporation of computer-aided manufacturing (CAM) techniques into production by adding the "supply-push" to the "demand-pull" factor which DOD currently provides to the aerospace industry.

ICAM is planting a seed of new technology that industry will absorb and implement. Industries' goal, of course, will be to raise the level of manufacturing technology in order to provide productivity gains and strengthen international competitive positions.

IV. ICAM DEFINITION

A. PAST BACKGROUND

In 1973 the Air Force generated a conceptual master plan (5) that identified and grouped some of the major functions of aerospace manufacturing. This plan was reviewed with industry leaders in June, 1974, and the effort stimulated an interchange of ideas but not a substantial long-range Air Force program.

Throughout 1975 the Air Force continued its own studies on computer-aided manufacturing. Impetus was added to this work by a memorandum from then-Deputy Secretary of Defense, W. P. Clements, to all military services but also circulated widely to industry. From the interchange of ideas which ensued, the Air Force learned that, beyond increased labor productivity, industry managers indicated that their decision to invest in CAM concepts would depend heavily on the extent of return on investment (ROI), maintenance of competitive position, greater design flexibility, and greater management control. Of these, industry considered the last as having the greatest payoff potential in CAM.

From a study of individual savings documented by industry in various non-integrated computer-aided manufacturing applications, the following savings potential was estimated:

Tool-design man-hours	80%
Fabrication assembly costs	44%
Maintenance costs	30%
Scheduling times	45%
Purchasing costs	35%
Inventory values	70%

However, the Air Force study concluded that, in general, while the above savings from individual applications are substantial, the major benefits will be realized when the individually-developed subsystems are integrated according to a plan that combines them into one manageable system.

A plan involving an iterative approach in developing and demonstrating such a system was presented by the Air Force, starting in April, 1976, in a series of public, industrial, and professional meetings. A summary of the written responses from the private sector suggested the following:

a. The Air Force should continue to refine its ICAM program.
b. The proposed modular model (architecture) of ICAM is the preferred approach.
c. The Air Force should assume a leadership role in computer-aided manufacturing (CAM).
d. Developed systems (hardware and software) must stand on their own merits for implementation by industry.
e. Strong university and research-institute involvement, as proposed, is essential.
f. Proposed ICAM management -- and technical -- advisory groups from the private sector should be supported.
g. A proposed ICAM demonstration facility is high-risk, will not be cost-effective, and should be eliminated.

The above considerations have been incorporated into the Air Force ICAM program as now formulated. It is expected that private sector review will play a continuing major role in program evaluation.

B. OBJECTIVES

The Integrated Computer-Aided Manufacturing (ICAM) program of the Air Force is a long-term project which includes the development of a number of modular subsystems designed to computer-assist various phases of design, fabrication and distribution processes, and the management hierarchy associated therewith, according to a prioritized master plan. At appropriate times, these modules, which are mutually compatible, will be combined to give a comprehensive control and management package which is capable of continual adjustment as production needs and state-of-the-art change.

In essence, the ICAM program provides "seed money" to advance the frontier of the technology in general. As a large customer with great potential for gain, the Department of Defense is willing to fund what might be termed "risk capital" for extending the technology. Industry is not geared to fund a program as ambitious in scope, primarily because of the long term of the pay-off. With government funding and industry cooperation, the technology can be developed and applied in a totally open manner; industry can acquire and apply the elements freely.

The specific objectives of the ICAM program are described in the Program Management Plan (6):

to perform manufacturing technology which will:

- *-- Reduce defense systems costs by developing and applying computer-aided manufacturing technology to the fabrication of defense materiel.*
- *-- Establish a model for the integrated application of computer technology to all phases of production/manufacturing.*
- *-- Improve the long-term competence, efficiency and responsiveness of American aerospace and related industries to defense needs.*
- *-- Provide a mechanism for Integrated Computer-Aided Manufacturing technology transfer to and within American industry.*
- *-- Validate and demonstrate the cost saving benefits and flexibility of ICAM on representative elements of Air Force Systems production.*

Benefits identified during the Air Force study to date validate the ability of CAM technology to reduce aerospace systems cost. A return-on-investment (ROI) goal of at least 25% for each subsystem module appears to be quite reasonable. Other objectives shown are also attainable but require particularly close interchange with industry in a continually-evolving process.

To foster this evolutionary activity, three baseline goals have been outlined:

-- Provide near-term pay-off

-- Establish a base for logical extension

-- Test software integration early

C. ATTRIBUTES

The ICAM program of the Air Force is visualized as a complex cooperative effort between the Department of Defense and industry. Among its constituent elements are system components (computer hardware; programming software; integration of new and existing systems, such as IPAD), utilitarian components (mechanism of operation; manuals; educational activity), and program implementation components (the development plan).

1. System Components

The concept defining the construction of the ICAM program system is called "manufacturing architecture", that is, the integrated collection of all the phases associated with the making of a product. Among these phases are the following:

- -- Executive control
- -- Management control, with its planning and reporting features
- -- Technical support
- -- Process control
- -- Direct manufacturing

There is, of course, continual interplay and communication up and down between these phases as well as interaction between various subphases within a phase. The nature of the subphases is dependent upon the type of manufacturing operation being performed. In Figure 1 are shown three common operations (milling, sheet metal forming, and assembly) and various representative subphases which could be associated therewith, grouped

according to the appropriate phase.

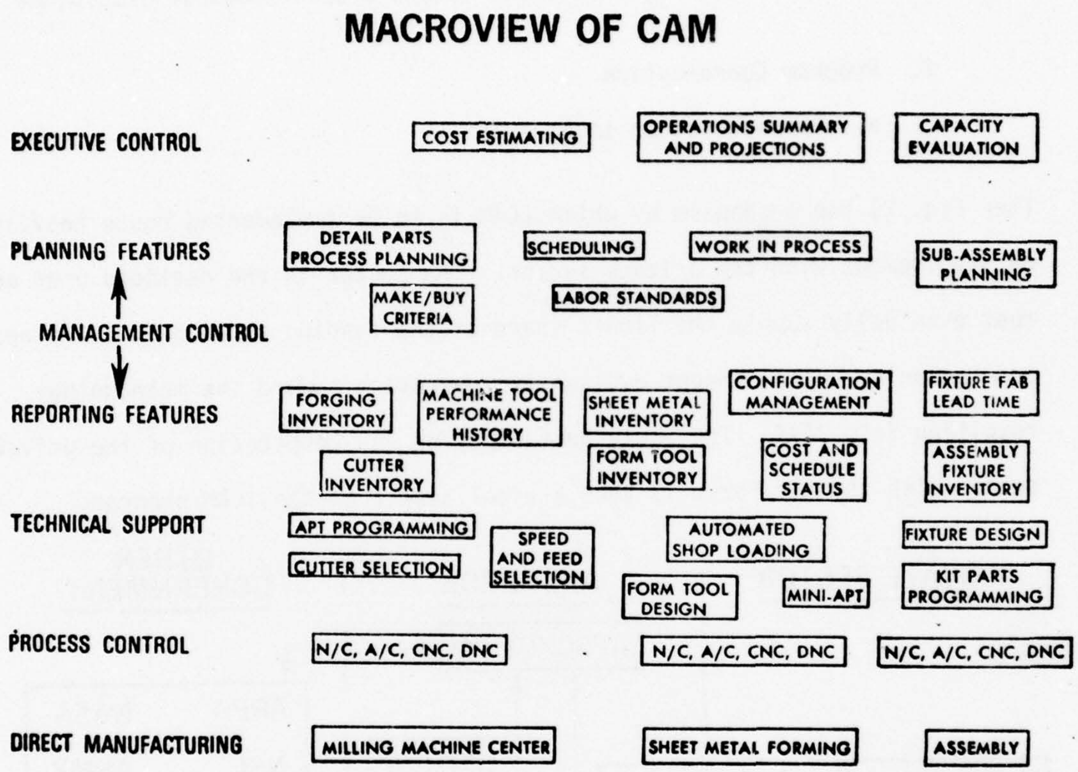


FIGURE 1. HIERARCHY OF ACTIVITIES TYPICAL OF MANUFACTURING

The functioning of each phase is centered around a computerized submodule of the architecture. Each submodule communicates and/or performs come constructive task using its own machinery, controlled by computer software and hardware which may be assigned exclusively to it or be shared with other submodules.

The ICAM program, through its manufacturing architecture, identifies the system structures, analyzes the many interactions and functions, and establishes the framework and standards to integrate the functional elements

into a unified construction to meet present and future needs. By this means it moves manufacturing management toward a technological discipline.

2. Program Coordination

a. Private Sector Involvement

(See Fig. 2) The mechanism by which ICAM is to be implemented rests heavily on involvement with the private sector. The sector is the destined user and must eventually supply the lion's share of the funding as each industry and manufacturing establishment evolves its operation toward the methodology resulting from ICAM. The early participation and cooperation of the private sector with the Air Force is thus a vital aspect of the ICAM program.

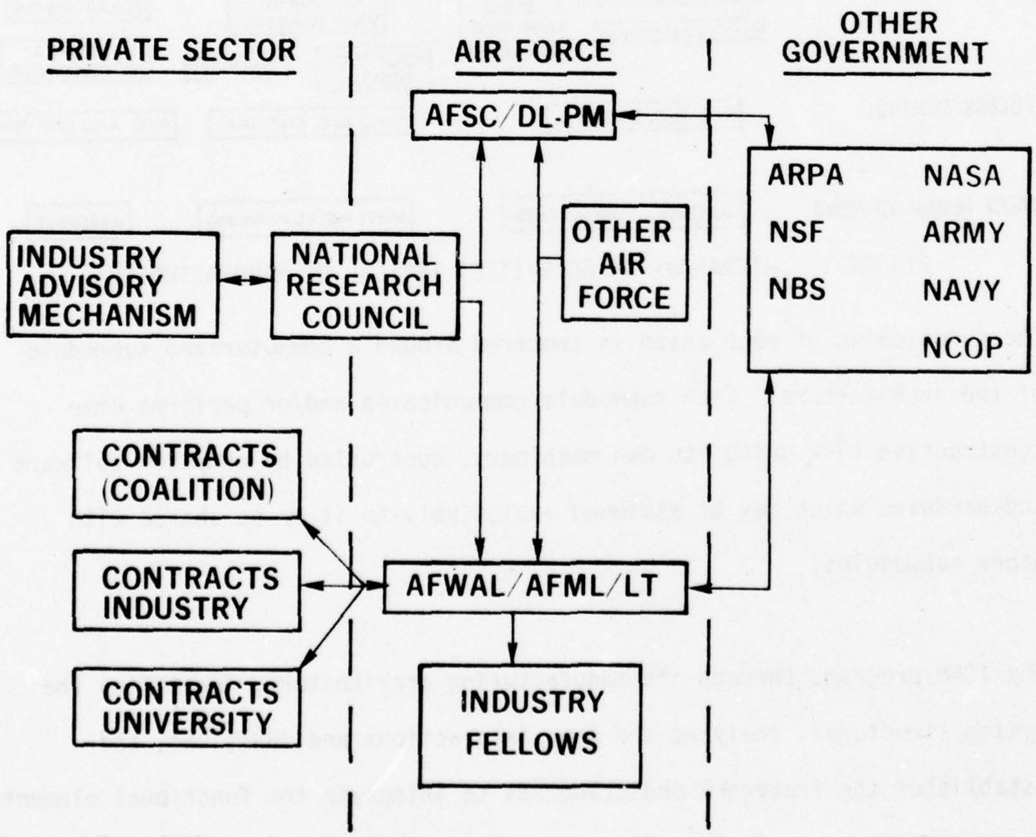


FIGURE 2. ICAM PROGRAM INTERFACES

As in the case of other Air Force Manufacturing Technology Projects, the ICAM development effort will be contracted out to the private sector. However, as a further incentive and to provide maximum communication, there will be mechanisms for program review by the private sector and an industry fellows program.

The private sector review procedure has been established with the National Research Council, Assembly of Engineering. Called the CAM (Computer-Aided Manufacturing) Committee, highly qualified representatives from aerospace and non-aerospace industries, universities, and private consultants meet on a periodic basis to analyze and review the program and make recommendations to the ICAM program manager.

The companion industry fellows program is one wherein selected individuals from many pertinent disciplines in the private sector are invited to work on the ICAM project managerial level for a one or two year period to acquaint themselves with all aspects of ICAM during its development. They then return to their own organizations, resulting in a mutually-beneficial information and services exchange.

In addition, as ICAM develops and various stages are reached that warrant substantial information exchange, various workshops will be scheduled to facilitate technology transfer. Other modes of such transfer can be via activities, such as seminars and conferences of industrial professional associations, like the Manufacturing Technology Advisory Group (MTAG).

b. Public Sector Involvement

The Air Force will interact with many branches of the government in the ICAM program. The roles of other agencies will range from actual contractual efforts, such as one conducted with the National Bureau of Standards (NBS), to joint program interfaces, such as the one with NASA on IPAD. The latter commitment includes a cooperative Memorandum of Agreement (MOA) between NASA's IPAD and the Air Force's ICAM. Also included in other interagency actions are the traditional roles such as program coordination and information exchange through the National Science Foundation (NSF) and the National Center for Productivity and Quality of Working Life (NCOP). In addition, during the initial ICAM proposals evaluations, the working team included representatives from the Army, Navy, NBS and NASA.

D. PROGRAM DEVELOPMENT

1. Phase Scheduling

In the initial Air Force study on manufacturing processes amenable to the ICAM program, 162 technical efforts in 11 areas were identified. These areas are depicted in Figure 3, which gives structure to the ICAM systems architecture. Distributed-processing and distributed-data bases will likely be employed. The outer ring of Figure 3 contains both shop-floor systems (fabrication, assembly, test-inspect-evaluate, materials handling) and support activities (control, external functions, design). The next inner ring provides access to the "smart" or intellectual systems required for planning and group technology (GT), plus simulation, mathematical, and

operations research (O.R.) techniques. The next inner ring symbolizes the computer system itself -- the mechanism required for the integration responsibility of ICAM. The center circle is the architecture or model of manufacturing.

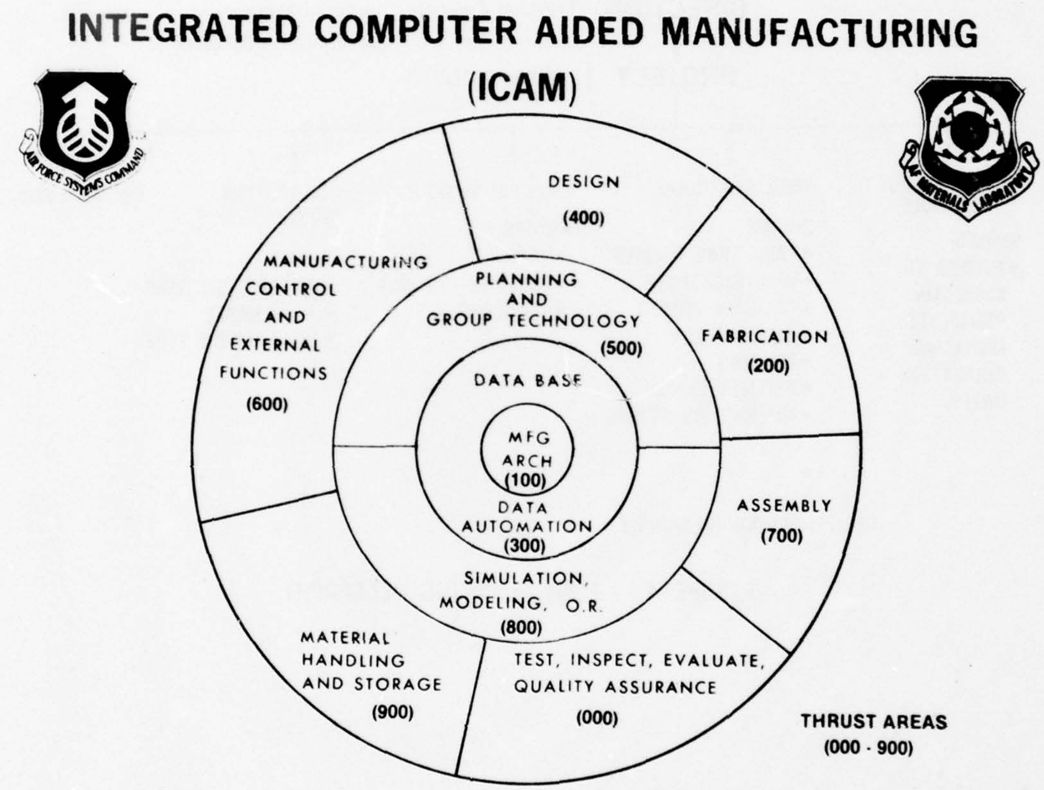
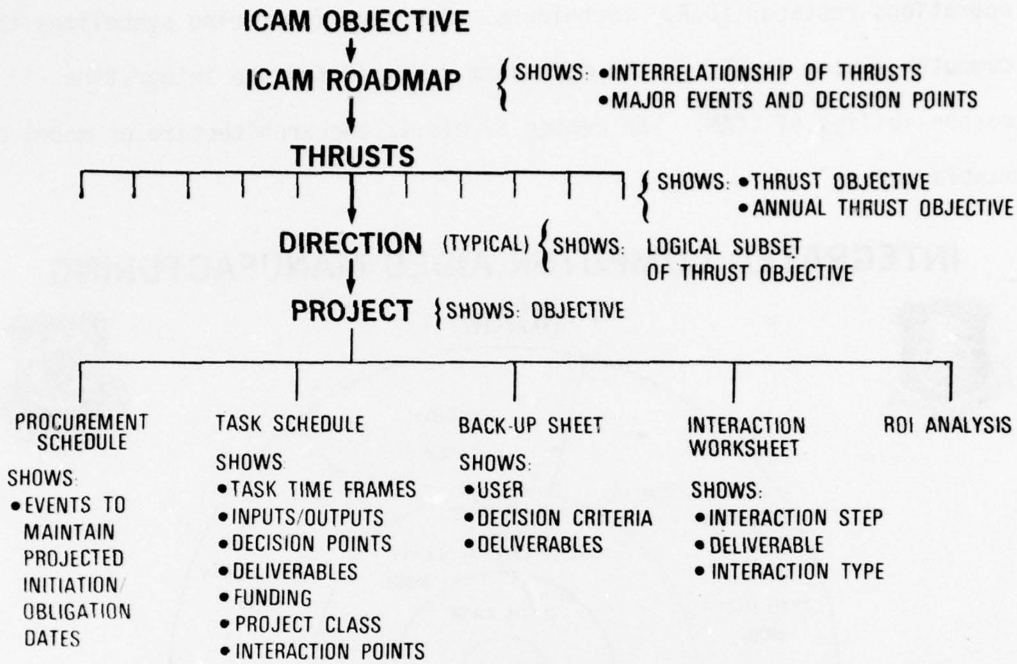


FIGURE 3. ICAM THRUSTS

ICAM planning is divided into "roadmap", "thrusts", and "project", so that tasks are continuously related to program direction and objective (see Fig. 4).



ICAM PLANNING HIERARCHY

FIGURE 4. ICAM PLANNING HIERARCHY

A preliminary stage of standards assessment was handled by the National Bureau of Standards under an ICAM contract. NBS considered standards in pure manufacturing, computer communications, languages, networks, etc., in order to identify potential conflicts which might impede use of ICAM or make its application awkward and inefficient. The final report is available from the program office (7).

To undertake, under the ICAM program in its initial five-year planning period, a significant number of the 162 identified technical efforts was determined to be unmanageable, costly and of too-high risk. Alternatively, it was decided to follow the "wedge" concept. Under the wedge concept, a single shop floor process which utilizes a significant portion of the manufacturing architecture, its modules and management and support hierarchy, is identified, analyzed and developed.

The shop floor process selected for the initial "wedge concept" treatment is sheet-metal processing (see Fig. 5 below). Unlike the machining technology,

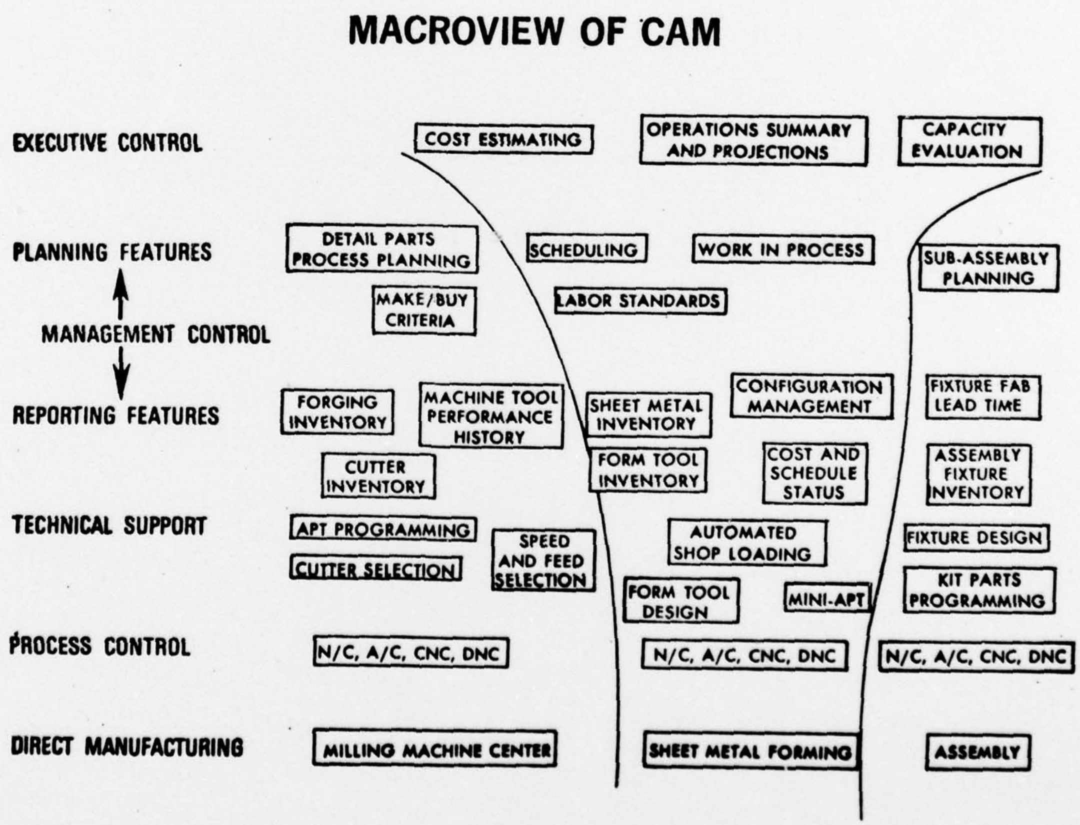


FIGURE 5. "WEDGE" THROUGH THE HIERARCHY OF MANUFACTURING

the aerospace industry has invested only to a moderate degree in advanced sheet-metal processing. Improving its operations in this area should directly, quickly and significantly reduce costs in future weapons systems, particularly when integrated with sheet-metal assembly (a logical and likely focus for a second "wedge").

The developmental procedure consists of identifying appropriate common technology and merging it with that characteristic of the "wedge" (here, sheet-metal or SM fabrication) in a "transition" phase, as shown in the ICAM Master Direction Roadmap (see Fig. 6 on following page).

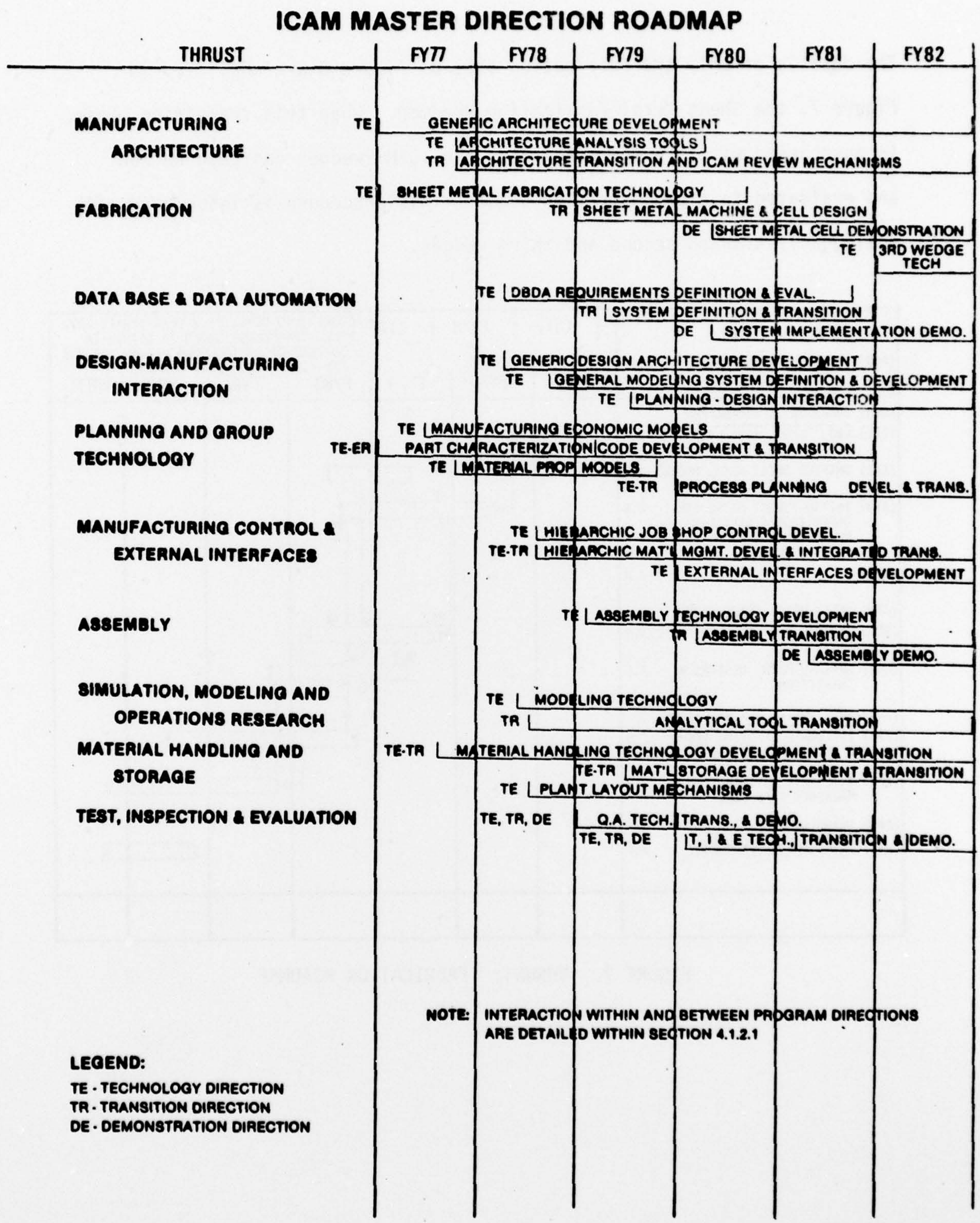


FIGURE 6. ICAM MASTER DIRECTION ROADMAP

The details of only the fabrication bars of Figure 6 are amplified in Figure 7, the Sheet Metal Fabrication Roadmap. When this transition phase is associated with a proper facility, the ICAM "wedge" can then be run and evaluated in a demonstration phase. This procedure is integrated with analogously-treated second and third wedges.

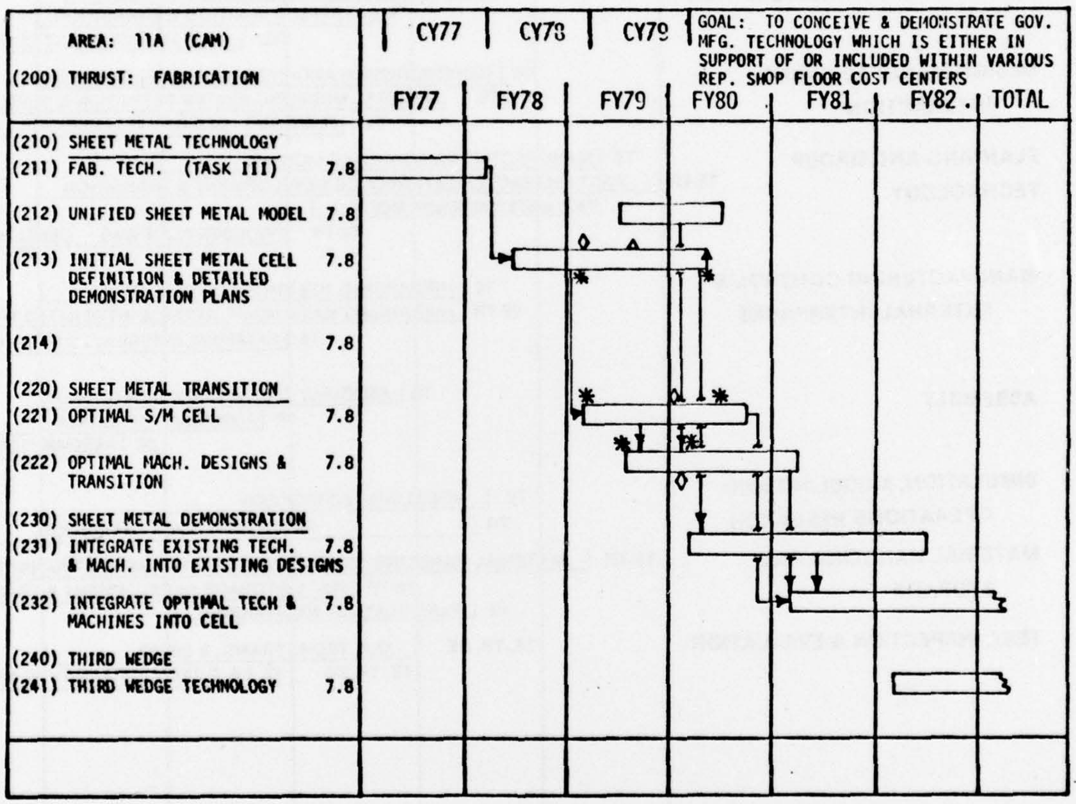


FIGURE 7. THRUST: FABRICATION ROADMAP

In its initial phases, which are concerned with the "sheet-metal fabrication wedge" as the first focus, certain benefits, as depicted in Figure 8, are envisioned. Over the three-to-four-year period available, other manufacturing shop floor areas will be addressed -- such as sheet metal discrete parts, mechanical fastening for metal assemblies, machining, welding, forging, castings, heat treatment, adhesive bonding, non-metallic processing (forming, cutting, molding, laminating), chemical milling, surface treatment, extrusion, brazing, etc.

SHEET METAL WEDGE BENEFIT MILESTONE EXAMPLES

	CY					
	77	78	79	80	81	82
COMMON BASIS FOR AEROSPACE PART CODING	△					
PRODUCTION READINESS CHECK LIST	△					
CONFIGURATION MANAGEMENT GUIDE FOR MANUFACTURING SYSTEM SOFTWARE		△				
SHEET METAL MANUFACTURING COST DATA		△				
SHEET METAL PARTS CODED - SUPPORT SOFTWARE			△			
MANUFACTURING SYSTEM SOFTWARE SIMULATOR TECHNIQUES			△			
GENERAL GENERATIVE PROCESS PLANNING MODEL				△		
GENERATIVE PROCESS PLANNING PROGRAMS FOR SHEET METAL PARTS					△	
OPTIMIZED SHEET METAL FABRICATION CELL					△	

FIGURE 8. SHEET-METAL "WEDGE" BENEFIT MILESTONES

In addition, mechanisms will be established to include emerging processes -- such as permanent joining methods (diffusion bonding, weld bonding, laser and plasma arc welding), detail fabrication (superplastic, flow, hydrostatic and thermoplastic forming), materials removal (laser, fluid jet, electron beam cutting), procured items (isothermal forging, powder metal, pultrusion), material treatment (laser and non-environmentally polluting treating), and assembly (bimetallic rivets and microwave curing).

The Air Force ICAM program considers computer-aided manufacturing a "total technology" for evolution. Some elements of it can be considered available today but needing more logical and systematic application. Other elements may require substantial modification or even a complete change in approach.

2. Anticipated Deliverables

The initial ICAM effort by industry is expected to generate a model (architecture) that displays all of the functions typical of batch manufacturing operations in general (not limited to aerospace companies). From past work it is believed that there will be differences between individual manufacturers chiefly in details of data manipulation and functional grouping of decisions and activities. Data extraction and regrouping or reorganization can provide the necessary accommodation.

On the conceptual level, the initial efforts should produce an architecture including "departmentalized elements" (such as marketing and market research,

personnel training, public relations, finance, legal counsel, and operation of shopfloor subsystems) only to the extent that they relate to sheet-metal fabrication and subassembly. Three architectural levels are expected to be delivered:

a. An abstract model of decisions, actions and activities

b. A functional model grouped into elements that could perform actions and activities

c. A detailed model complete with required data

Each level will be constructed according to the rules of a cell-modeling technique (8). In addition to the models themselves, deliverables also include specifications to test their validity.

On the operation level, deliverables will include specifications that will support all of manufacturing from part design to fabrication and assembly, a walk-through of the specifications for sheet-metal parts, an indication of existing system match, and a possible plan for the future.

Specific deliverables for the first two years of the program are reflected in the milestones shown on the program schedule (see Fig. 9):

-manufacturing cost predicted for design use
-plans for initial sheet metal cell demo
-sheet metal group technology character code
-plans for optimized sheet metal cell
-computer tools for architecture transfer and demo
-generic architecture (sheet metal -- assembly)

-verified manufacturing architecture model
-production floor robot fabrication cell
-demo for initial sheet metal cell

In years three, four, and five, the sheet metal demonstration includes the initial assembly cell and a generative process plan, and the program moves through systems definition, implementation and complete demonstration (see Figs. 8 and 9). Tasks include simulation, modeling, and the integration of an overall manufacturing control system. Testing, inspection, and evaluation processes are scheduled, as well as numerous technical briefings, meetings and reports on a modular as well as timely basis.

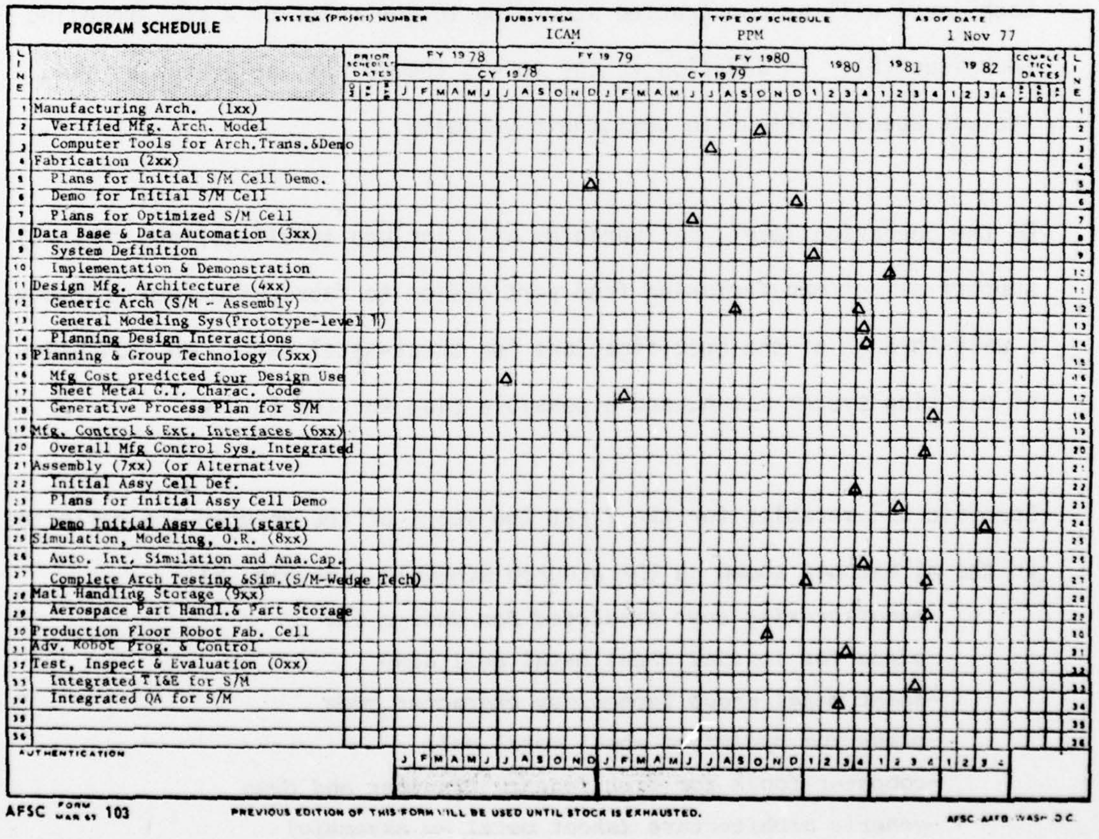


FIGURE 9. PROGRAM SCHEDULE

ICAM will deliver a planning ability to allow engineers not only to design a part optimally, but also to subject the part to a performance evaluation, and to quickly plan its most economical fabrication within constraints of schedule, availability of raw materials, and variability in materials and/or processes. Design and processing information will likely become available in standard data formats, deliverable promptly to management for "what-if" simulation ranging from risk analysis to plant layout.

The primary deliverable of the program is simply the demonstration that ICAM, properly formatted and structured, works, and can be harnessed to provide very substantial management benefits.

V. ICAM PAY-OFF

Along the way to integrated computer-aided manufacturing, many individual efforts will offer significant short-term return-on-investment (ROI) benefits. However, the real pay-off in ICAM will be achieved through the integration effort and the demonstration by private industry of totally integrated manufacturing systems in production facilities.

In its ultimate integrated form, ICAM would allow production only barely within our ability to comprehend now, managerially and technically. Figure 10 shows the ICAM "Dream Chart" of the future manufacturing environment.

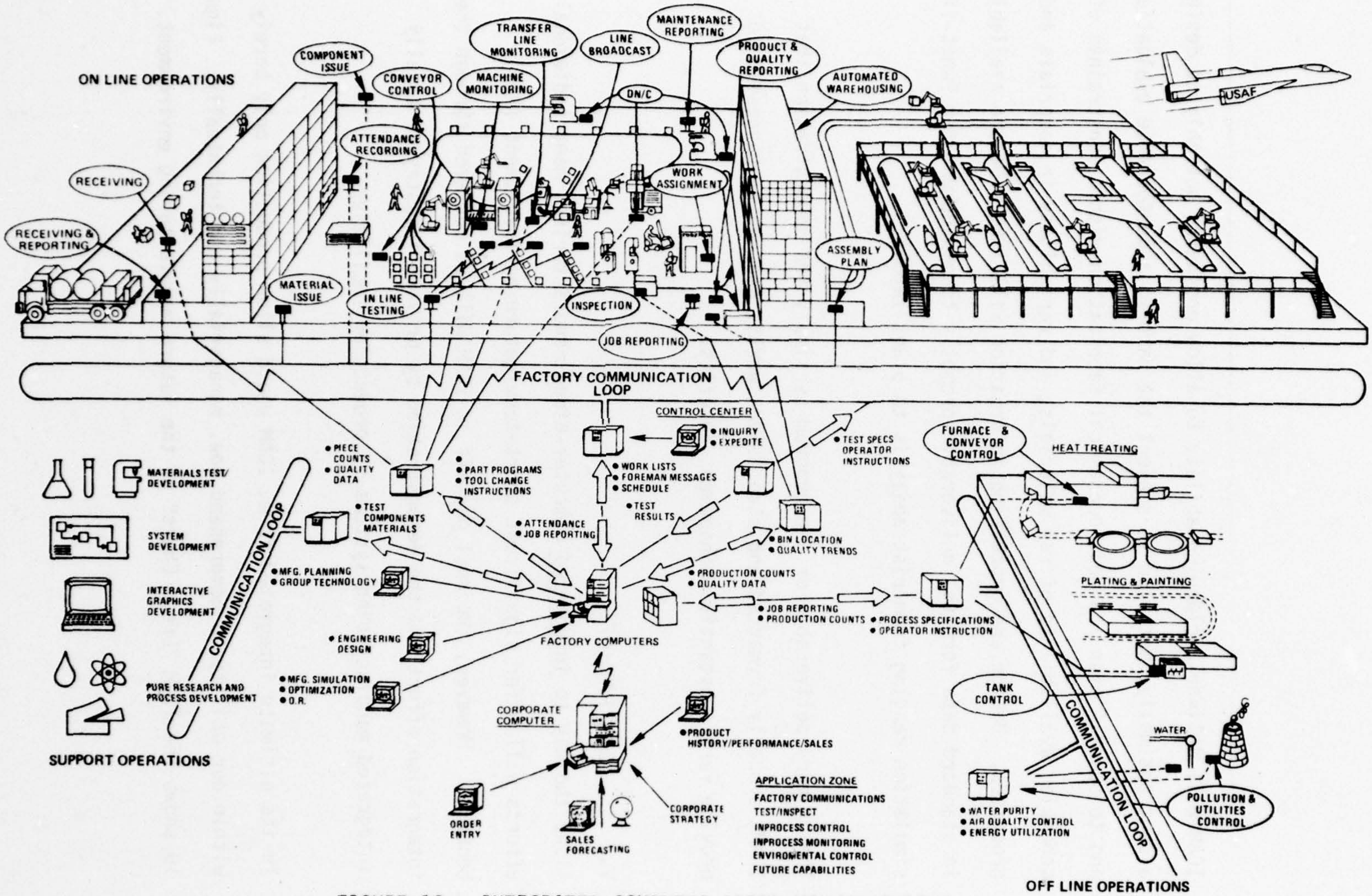


FIGURE 10. INTEGRATED COMPUTER AIDED MANUFACTURING

ICAM paypffs will be multi-dimensional and will occur in both "hard" technical areas and in more intangible ways as a result of changes in attitude and organizational thinking. While the latter is difficult to measure or predict in dollar terms, and will vary from organization to organization, a positive result in terms of improved productivity is virtually assured. For example, efficiency will be improved simply by the replacement of the computer "applications" concept of non-synchronized departmental functions in favor of a controlling data base concept. The demonstrated advantages of integration will thus bring about a change in management philosophy and an end to numerous inefficiencies.

Prediction is simpler in the "hard" areas and relatively easy to demonstrate in technical projects like robotics. One major aerospace corporation has estimated that their five-year internal ICAM project will result in a 1-2% reduction in their overhead. Although the percentage seems small at first glance, in large corporations this fraction is very significant in dollars. The program for the DoD bulk buy of Numerical Controlled Machine Tools in 1956 required an investment of $40 million, but is providing a multi-billion-dollar payoff. An ICAM investment of $75 million should also provide a multi-billion-dollar payoff.

Modern surveys of relative productivity indicate that a factor on the order of 28% of improvement in productivity is due to new technology, and that improved technology is by far the largest factor in productivity improvement.

ICAM is a major investment in new technology, not for the sake of the knowledge, but to insure that the resultant significant productivity improvement is placed on the agenda.

Meeting this goal requires a long-range aim. However, work done in other countries indicates that with the proper foundation, the U.S. can regain a manufacturing leadership role in the 1990's. The basic requirement today is commitment and cooperation for the systematic development of a logical approach to manufacturing automation and computer management.

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